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THE CALCULATION OF THE NORM IN IGNEOUS ROCKS

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In presenting to successive classes of students in petrography the method of calculating the norm for igneous rocks under the quantitative classification of Cross, Iddings, Pirsson, and Washington, the writer has found such a selection of calculated analyses as is here given, accompanied by discussion, of great service. For practice in calculation the collection of analyses with their norms by Dr. H. S. Washington given in *Professional Papers 14 and 28* of the U. S. Geological Survey is invaluable. Of the calculated analyses which follow, all but two are taken from *Professional Paper 14*. By using the tables given at the end of the *Quantitative Classification of Igneous Rocks*¹ the arithmetical work in calculating the norms is very greatly lessened. The first set of tables, prepared by Professor J. F. Kemp and originally published in the *School of Mines Quarterly*,² gives the molecular proportions for the percentage figures of the several oxides recorded in rock analyses. The second set of tables in the *Quantitative Classification of Igneous Rocks* gives the percentage weights for various proportions of molecules of the standard rock-making minerals. The molecular proportions may be calculated by dividing the percentage figures for each oxide by the molecular weight of the oxide. Thus for 65.70 per cent. silica the molecular proportion is 1.095, the molecular weight of SiO_2 being 60. The molecular proportion for 15.40 per cent. soda is .248, the molecular weight of Na_2O being 62. As a preliminary step in the calculation of an analysis the molecular proportions for each oxide must be looked up in the tables. Small amounts of MnO (.001 to .005), and NiO are to be used as FeO ;

¹ Cross, Iddings, Pirsson, and Washington, *Quantitative Classification of Igneous Rocks* (Chicago: The University of Chicago Press, 1903), pp. 237-59.

² J. F. Kemp, "The Recalculation of the Chemical Analyses of Rocks," *School of Mines Quarterly*, XXVII, 75-88.

and in the same manner small amounts of BaO and SrO are to be added in with the CaO. If Cr_2O_3 does not amount to .002 it is to be added in with Fe_2O_3 . For the calculation of a rock analysis we then start with the molecular proportions of the ten oxides SiO_2 , Al_2O_3 , Fe_2O_3 , FeO, MgO, CaO, Na_2O , K_2O , TiO_2 , and P_2O_5 , which are contained in nearly every rock, and we may also have present ZrO_2 , SO_3 , Cl, F, and CO_2 , besides H_2O ; and, in smaller amounts, MnO and NiO to be summed in with FeO; BaO and SrO, to be added to CaO; and Cr_2O_3 which is to be counted as Fe_2O_3 . ZrO_2 , Cr_2O_3 in amount more than .002, TiO_2 , P_2O_5 , SO_3 , Cl, CO_2 , and F, when they are present, are first calculated as minor inflexible molecules. Their calculation as zircon, chromite, ilmenite, apatite, noselite, sodalite, calcite, and fluorite presents no difficulty, for the method of procedure is always the same. The eight oxides SiO_2 , Al_2O_3 , Fe_2O_3 , FeO, MgO, CaO, Na_2O , and K_2O are of much greater importance in the calculation of the norm, for any one of these oxides in a given analysis is disposed of with regard to the relative quantities of all the others. The difficulty in presenting to the student the method of procedure in its entirety lies in the fact that a rather long series of considerations is to be put before him at the very outset. The aim of the writer in the present paper is to develop little by little with the aid of examples and discussions the condensed, precise statement of the authors of the *Quantitative Classification of Igneous Rocks*, pp. 188-96.

The simplest cases are those in which SiO_2 and Al_2O_3 are present in relatively large amounts so that they meet all claims upon them and are not exhausted. Al_2O_3 remaining over is corundum, and SiO_2 remaining over after all the allotments is quartz. With SiO_2 present in abundance Al_2O_3 may meet all the claims of K_2O , Na_2O , and CaO upon it; or it may satisfy K_2O , Na_2O , and part of the CaO. Again it may satisfy only K_2O and part of the Na_2O ; or, rarely, only part of the K_2O . So the treatment varies.

The norm minerals of the two groups, which figure in the calculation, with the abbreviations for their names, and their formulas, are as follows. The table is intended to set forth the relative importance of their several rôles in the norm.

I. SALIC GROUP

Dominantly Siliceous and Aluminous

A. Quartz.....	SiO ₂	Q.
Corundum.....	Al ₂ O ₃	C.
Orthoclase.....	K ₂ O.Al ₂ O ₃ .6SiO ₂	or.
Albite.....	Na ₂ O.Al ₂ O ₃ .6SiO ₂	ab.
Anorthite.....	CaO.Al ₂ O ₃ .2SiO ₂	an.
Leucite.....	K ₂ O.Al ₂ O ₃ .4SiO ₂	lc.
Nephelite.....	Na ₂ O.Al ₂ O ₃ .2SiO ₂	ne.
Kaliophilite.....	K ₂ O.Al ₂ O ₃ .2SiO ₂	kp.
B. Minor inflexible molecules		
Sodalite.....	3(Na ₂ O.Al ₂ O ₃ .2SiO ₂).2NaCl	so.
Noselite.....	2(Na ₂ O.Al ₂ O ₃ .2SiO ₂). Na ₂ SO ₄	no.
Zircon.....	ZrO ₂ .SiO ₂	Z.

Of the salic minerals kaliophilite is very rare, while sodalite, noselite, and zircon are much less rare but still unusual. (See note at end of paper on the substitution of halite, NaCl [HI], and thenardite [Th], Na₂SO₄, for sodalite and noselite, respectively, among the salic minerals.)

II. FEMIC GROUP

A. Diopside.....	CaO.(MgFe)O.2SiO ₂	di.
Hypersthene.....	(MgFe)O.SiO ₂	hy.
Olivine.....	2(MgFe)O.SiO ₂	ol.
Acmite.....	Na ₂ O.Fe ₂ O ₃ .4SiO ₂	ac.
Sodium metasilicate.....	Na ₂ O.SiO ₂	ns.
Potassium metasilicate.....	K ₂ O.SiO ₂	ks.
Wollastonite.....	CaO.SiO ₂	wo.
Ackermanite.....	4CaO.3SiO ₂	am.
B. Minor inflexible molecules		
Magnetite.....	Fe ₂ O ₃ .FeO	mt.
Ilmenite.....	FeO.TiO ₂	il.
Chromite.....	FeO.Cr ₂ O ₃	cm.
Hematite.....	Fe ₂ O ₃	hm.
Titanite.....	CaO.TiO ₂ .SiO ₂	tn.
Perovskite.....	CaO.TiO ₂	pf.
Rutile.....	TiO ₂	ru.
Apatite.....	3CaO.P ₂ O ₅ . $\frac{\text{CaCl}_2}{3}$ or	
	3CaO.P ₂ O ₅ . $\frac{\text{CaF}_2}{3}$	ap.
Fluorite.....	CaF ₂	ft.
Calcite.....	CaO.CO ₂	cc.
Pyrite.....	FeS ₂	pr.

Of the minor inflexible molecules in the femic group magnetite, ilmenite, and apatite are very common. The others occur occasionally.

Among the femic minerals diopside, hypersthene, and olivine appear very often in the norm, acmite and wollastonite are not unusual, while ackermanite, potash metasilicate, and soda metasilicate are rare. Among the minor inflexible mineral molecules magnetite, ilmenite, and apatite commonly appear; hematite, titanite, perovskite, fluorite, and pyrite are not infrequently met with; and chromite, rutile, and calcite are rare.

The minor inflexible molecules, with the exception of magnetite and hematite, will not be considered at the outset. They are not present in the first eight of the series of calculated analyses, but were they present they would claim attention in the first place. Their calculation is simple, but the form of presentation gains in clearness by bringing them in only after the main features of the calculation have been dealt with. The key to the disposal to be made of the important oxides SiO_2 , Al_2O_3 , Fe_2O_3 , FeO , MgO , CaO , Na_2O , and K_2O lies in the relative affinities of K_2O , Na_2O , CaO , MgO , FeO , and Fe_2O_3 , for SiO_2 and Al_2O_3 . The point of prime importance is the amount of the two oxides SiO_2 and Al_2O_3 . In the simpler cases K_2O , Na_2O , and CaO are to be allotted to Al_2O_3 and SiO_2 in the right proportions for the formation of the feldspars. K_2O has the strongest affinity for Al_2O_3 and SiO_2 . It therefore has the first claim, and, after it has taken its quota of these oxides, Na_2O , with the next strongest affinity for them, receives its quota. Lastly CaO with an affinity less than the others is to be satisfied. The oxides MgO and FeO do not unite with both Al_2O_3 and SiO_2 at the same time in the normative minerals. They combine with SiO_2 alone to form hypersthene and olivine, or with CaO and SiO_2 to form diopside.

In Analysis A the simplest possible case is given. SiO_2 and Al_2O_3 are abundant, occurring in sufficient amounts to answer every claim of K_2O , Na_2O , and CaO upon them. Al_2O_3 remaining over is corundum, and SiO_2 remaining over is quartz. TiO_2 and P_2O_5 are not present, and no other elements occur which should be calculated as the minor inflexible mineral molecules. Fe_2O_3 , FeO , and MgO not being present, there is nothing to be allotted for femic minerals.

In accordance with its formula $K_2O.Al_2O_3.6SiO_2$, in the proportions 1:1:6, for orthoclase, K_2O , 53, takes 53 Al_2O_3 and six times as much SiO_2 . In the same way albite, $Na_2O.Al_2O_3.6SiO_2$, in the proportions 1:1:6, with Na_2O , 60, takes 60 molecular-proportion units of Al_2O_3 and 6×60 of SiO_2 . Anorthite, $CaO.Al_2O_3.2SiO_2$, in the proportions 1:1:2, is made with 20 CaO , 20 Al_2O_3 , and 40 SiO_2 . Of Al_2O_3 , 3 molecular-proportion units are left for corundum. Of SiO_2 , 557 molecular-proportion units are left to form quartz. The percentage weights for the calculated minerals have been obtained from the second set of tables, pages 247-59, by looking up for orthoclase (or), the amount of K_2O , 53; for albite (ab), the amount of

ANALYSIS A

TOSCANOSE (APLITE). *Professional Paper 14*, p. 172, No. 122

Dargo, Victoria, Australia

Percent- age	SiO_2 76.48	Al_2O_3 13.94	Fe_2O_3 Trace	FeO None	MgO 0.01	CaO 1.08	Na_2O 3.70	K_2O 4.90	H_2O 1.01	Sum 101.12	
Molecular Proportions	1.275	.136				.020	.060	.053	Salic Minerals		Femic Minerals
	318 360 40 557	53 60 20 3				20	60	53	or ab an C Q	29.5 31.4 5.6 .3 33.4	
NOTE.—or .053 \times 556 = 29.468 written as 29.5 ab .060 \times 524 = 31.440 written as 31.4 an .020 \times 278 = 5.560 written as 5.6 C .003 \times 102 = .306 written as .3 Q .557 \times 60 = 33.420 written as 33.4									Sal. H_2O	100.2 1.01	
									Sum	101.21	

Na_2O , 60; for anorthite (an), the amount of CaO , 20; for corundum (C), the amount of Al_2O_3 , 3. To get quartz we multiply the amount of SiO_2 left over for it (557), by 60, the molecular weight of quartz. With abundant silica then and with Al_2O_3 greater than $K_2O + Na_2O + CaO$ we make orthoclase, albite, anorthite, corundum with extra Al_2O_3 , and quartz with extra SiO_2 .

The sum of the percentage figures of the analysis, H_2O being 1.01, is 101.12. The sum of the calculated minerals in the norm with H_2O added in is 101.21, and for every calculated analysis these two should correspond as closely as 1 per cent. or 2 per cent. The correspondence cannot be numerically absolute, but it gives us a valuable check on the correctness of the calculation.

In Analysis B we have the same condition, except that FeO and Fe₂O₃ are both present. After the allotment for the feldspars has been made, and Al₂O₃ remaining over has been given to corundum (C), Fe₂O₃ and FeO, in the proportion 1:1, are allotted to magnetite (mt), and silica remaining over is quartz (Q).

ANALYSIS B

TEHAMOSE (QUARTZ PORPHYRY). *Professional Paper 14*, p. 132, No. 10
Tamaya, Chile

Percent- age {	SiO ₂ 75.93	Al ₂ O ₃ 13.26	Fe ₂ O ₃ 1.47	FeO 0.68	MgO None	CaO 1.11	Na ₂ O 3.13	K ₂ O 3.19	H ₂ O 0.44	Sum 99.72	
Molecular Proportions	1.266	.130	.009	.010		.020	.050	.034	Salic Minerals		Femic Minerals
	204 300 40 722	34 50 20 26	 9	 9		 20	 50	34	or 18.9 ab 26.2 an 5.6 C 2.7 Q 43.3		mt 2.1
NOTE.—1 FeO neglected.									Sal. 96.7 Fem. 2.1 H ₂ O .44		Fem. 2.1
									Sum 99.24		

The calculation of Analysis C is like the preceding one in its allotments for orthoclase (or), albite (ab), anorthite (an), corundum (C), and magnetite (mt). Then there remain over, besides SiO₂, 2 molecular-proportion units of MgO, and 15 of FeO. These are allotted to hypersthene (hy), (MgFe)O.SiO₂, in the proportion (MgFe)O:SiO₂ as 1:1. MgO and FeO are used in hypersthene in the ratio in which they happen to stand when this mineral comes to be made. Here the ratio is 2:15. In later analyses MgO and FeO will be introduced into the calculations in the minerals diopside (di), and olivine (ol), as well as in hypersthene. When all three or any two of them are to be made MgO and FeO are to stand in all of them in the same proportion in which they were used in the first of these minerals calculated at the time. In Analysis C it will be noted that hypersthene is the sum of two parts, MgO.SiO₂ and FeO.SiO₂, each of which is to be found separately. FeO.SiO₂ may be looked up in the table on p. 254. MgO.SiO₂ is equal to 100 times the amount of MgO. These findings are added together for hypersthene.

ANALYSIS C
ALASKASE (RHYOLITE). *Professional Paper 14*, p. 130, No. 1
Madison Plateau, Yellowstone National Park

Percentage Molecular Proportions	{ }	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O	Sum	Femic Minerals
		75.19 1.253	13.77 .135	0.61 .004	1.37 .019	0.09 .002	0.68 .012	3.83 .061	3.33 .035	0.65	90.83	
		210 366 24	35 61 12 27	4	4		12	61	35	or ab an C	19.5 32.0 3.3 2.8	mt hy
		17 636			15	2				Q	38.2	$\left\{ \begin{array}{l} \text{MgO.SiO}_2 \text{ } .200 \\ \text{FeO.SiO}_2 \text{ } 1.98 \end{array} \right\}$
										Sal. Fem. H ₂ O	95.8 3.1 .65	Fem. 3.1
										Sum	99.55	

In Analysis D after the allotment for magnetite (mt), 3 molecular-proportion units of Fe_2O_3 are left over. These go in as hematite (hm). Then MgO , 4, and FeO , 6, are left over. They are used to make a hypersthene free from FeO . In like manner in other analyses hypersthene might be made of $\text{FeO} \cdot \text{SiO}_2$, the other component $\text{MgO} \cdot \text{SiO}_2$ not being available.

In analysis E the allotments are made for orthoclase (or), albite (ab), anorthite (an), and magnetite (mt). CaO remaining is allotted, with MgO , FeO , and SiO_2 , to diopside (di), $\text{CaO} \cdot (\text{MgFe})\text{O} \cdot 2\text{SiO}_2$, the proportions of the constituents by the formula being 1:1:2. MgO and FeO together are equal to CaO , and are used in the proportion in which they are found when the mineral comes to be made. Here the ratio is 36:5, or nearly 7:1. The silica is twice the lime. MgO and FeO remaining are used for hypersthene (hy), still in the same ratio 7:1 (see p. 63, line 11). SiO_2 is allotted by hypersthene in amount equal to $\text{MgO} + \text{FeO}$.

It is to be noted that we cannot have diopside and corundum together in the norm.

Analysis F presents the case where K_2O is allotted with Al_2O_3 and SiO_2 to orthoclase (or), and Na_2O is allotted to Al_2O_3 and SiO_2 for albite (ab). Al_2O_3 remaining, 9 units, can satisfy only 9 units of CaO for anorthite (an). Then CaO remaining is allotted to diopside (di), as far as MgO and FeO are available. Of CaO 27 molecular-proportion units are still left. These take an equal amount of SiO_2 for wollastonite (wo), $\text{CaO} \cdot \text{SiO}_2$, 1:1. It is clear that since MgO and FeO were not present in sufficient amounts to make diopside with all the lime, there remain none of these constituents for hypersthene or olivine. So then with wollastonite there will be no hypersthene or olivine.

We now come to Analysis G, in which with abundant SiO_2 , the Al_2O_3 covers K_2O and partly covers Na_2O . Orthoclase (or), is made, and albite (ab), as far as the Al_2O_3 admits of it. Soda, Na_2O , 5 units, left over, there being no Al_2O_3 available for it, takes Fe_2O_3 and SiO_2 for acmite (ac), $\text{Na}_2\text{O} \cdot \text{Fe}_2\text{O}_3 \cdot 4\text{SiO}_2$, in the proportions, 1:1:4. It is clear that with acmite there will be no anorthite. After the allotment is made for magnetite (mt), the CaO takes MgO , FeO , and SiO_2 for diopside (di). The remaining MgO and FeO are used

ANALYSIS E
TOSCANOSE (GRANITE). *Professional Paper 14*, p. 168, No. 92
Riesengebirge, Silesia

Percentage	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O	Sum	Femic Minerals
Molecular Proportions	71.53	13.55	1.20	0.88	1.45	3.21	2.61	3.95	1.75	100.13	
	1.192	.133	.007	.012	.036	.057	.042	.042			
	252	42				49	42	42	or ab an	23.4 22.0 13.6	mt 1.6
	252	42				8					di 1.8
	98	49	7	7	7						hy 3.4
	16			1							CaO.SiO ₂ .93 MgO.SiO ₂ .700 FeO.SiO ₂ .13
	33			4	29						MgO.SiO ₂ 2.900 FeO.SiO ₂ .53
	541								Q	32.5	
									Sal. Fem. H ₂ O	91.5 6.8 1.75	Fem. 6.8
									Sum	100.05	

ANALYSIS F
ALASKOSE (GRANITE). *Professional Paper 14*, p. 126, No. 4
Waushara, Wis.

Percentage	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O	Sum	
	74.62	10.01	3.85	1.72	0.33	2.43	3.33	3.38	0.24	99.91	
Molecular Proportions	1.244	.008	.024	.024	.008	.044	.053	.036			Femic Minerals
	216 318 18	36 53 9	24	24 0		9	53	36	or ab an	20.0 27.8 2.5	
	16				8	8					mt 5.6 di 1.7 wo 3.1
	27 649					27			Q	39.0	(CaO.SiO ₂ .93 MgO.SiO ₂ .800 FeO.SiO ₂ .00
									Sal. Fem. H ₂ O	89.3 10.4 .24	Fem. 10.4
									Sum	99.94	

OMEOSE (LIPARITE). ANALYSIS G
Professional Paper 14, at bottom of p. 142, No. 3
Cabo de Gata, Spain

Perce age	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	HO ₂	Sum	Fenic Minerals
	71.12	13.35	1.37	1.28	0.47	0.32	2.02	9.82	1.13	100.88	
Molecular Proportions	1.185	.131	.009	.018	.012	.005	.032	.104	Salic Minerals		
	624	104					27	104	or	57.8	ac 2.3
	102	27	5	4			5		ab	14.2	mt .9
	20		4								di 1.2 { CaO.SiO ₂ .58 MgO.SiO ₂ .200 FeO.SiO ₂ .40
	10			3	2	5					hy 2.5 { MgO.SiO ₂ 1.000 FeO.SiO ₂ 1.45
	21			11	10				Q	20.9	
	348								Sal. 92.9		Fem. 6.9
									Fem. 6.9		
									H ₂ O 1.13		
									Sum 100.93		

for hypersthene (hy), in the same proportion in which they stood for diopside.

Analysis H presents the case where after making orthoclase (or), albite (ab), and acmite (ac), Na_2O still remains over. This is allotted with SiO_2 to form sodium metasilicate (ns), $\text{Na}_2\text{O} \cdot \text{SiO}_2$, 1:1. It is rarely found necessary to introduce sodium metasilicate in this way.

Case I presents the inflexible mineral molecules ilmenite, titanite, apatite, and fluorite. Sodium metasilicate is introduced, and potassium metasilicate (ks), $\text{K}_2\text{O} \cdot \text{SiO}_2$, as well—an extremely rare occurrence. The minor inflexible molecules in the femic group are magnetite, chromite, hematite, ilmenite, titanite, perovskite, rutile, apatite, fluorite, calcite, and pyrite. Magnetite and hematite have been introduced in preceding analyses; chromite is made in Analysis S, perovskite in Analysis S, rutile is considered in the present analysis, calcite appears in Analysis O, and pyrite in Analysis K. In the salic group we have the minor inflexible molecules zircon, sodalite, and noselite. Zircon appears in Analysis M, and sodalite and noselite in Analysis O.

Following the order stated on p. 188, sec. 3, in the *Quantitative Classification of Igneous Rocks*, Cr_2O_3 not being present, we first allot FeO to TiO_2 for ilmenite (il), in the proportion 1:1. TiO_2 remaining over takes CaO and SiO_2 for titanite (tn), $\text{CaO} \cdot \text{TiO}_2 \cdot \text{SiO}_2$, in the proportion 1:1:1. We are working with an analysis in which the amount of SiO_2 is sufficient to meet all claims upon it. If silica were not abundant TiO_2 remaining over after the allotment for ilmenite would take CaO for perovskite (pf), $\text{CaO} \cdot \text{TiO}_2$, in the proportion 1:1. Such a case is given in Analysis S. Here if TiO_2 after the allotments for ilmenite and titanite still remained over, it would be considered as rutile (ru), TiO_2 . In the next place P_2O_5 takes $3\frac{1}{3}$ times as many units of CaO as there are units of P_2O_5 , and $\frac{1}{3}$ as much F or Cl, for apatite (ap), $3\text{CaO} \cdot \text{P}_2\text{O}_5 + \frac{\text{CaCl}_2}{3}$ or $3\text{CaO} \cdot \text{P}_2\text{O}_5 + \frac{\text{CaF}_2}{3}$ in the ratio $\text{CaO}:\text{P}_2\text{O}_5$ as $3\frac{1}{3}:1$, and F or Cl, to satisfy CaO, equal to $\frac{1}{3}\text{P}_2\text{O}_5$. In the next place fluorine ($F=26$), takes $\frac{1}{2}$ as much CaO for fluorite (ft), CaF_2 . After these minor inflexible molecules have been adjusted K_2O is allotted for orthoclase with the

available Al_2O_3 , 93, and SiO_2 . The K_2O remaining over is allotted to potassium metasilicate (ks), $\text{K}_2\text{O}.\text{SiO}_2$, with SiO_2 , in the ratio 1:1. After all the K_2O has been used Na_2O takes Fe_2O_3 , as far as Fe_2O_3 is available (there being no Al_2O_3 left to unite with it), and SiO_2 , for acmite. Na_2O still remaining over is sodium metasilicate. CaO remaining after the foregoing assignments takes MgO and FeO in the requisite amounts, and in the ratio in which they stand, 8:0, for diopside (di). MgO remaining, there being no FeO , is allotted to hypersthene, and the SiO_2 which has not been used is quartz.

All the analyses thus far presented, from A to I inclusive, have been those in which SiO_2 is abundant. The calculation of analyses in which SiO_2 is relatively low is usually more difficult. Orthoclase (or), $\text{K}_2\text{O}.\text{Al}_2\text{O}_3.6\text{SiO}_2$, requires more silica than leucite (lc), $\text{K}_2\text{O}.\text{Al}_2\text{O}_3.4\text{SiO}_2$, and leucite requires more silica than kaliophyllite (kp), $\text{K}_2\text{O}.\text{Al}_2\text{O}_3.2\text{SiO}_2$. In the same way albite (ab), $\text{Na}_2\text{O}.\text{Al}_2\text{O}_3.6\text{SiO}_2$ requires more silica than nephelite (ne), $\text{Na}_2\text{O}.\text{Al}_2\text{O}_3.2\text{SiO}_2$. It should be noted that the ratio between K_2O and Al_2O_3 is always as 1:1 in orthoclase, leucite, and kaliophyllite, and that the ratio between Na_2O and Al_2O_3 is always 1:1 in albite and nephelite. Hypersthene (hy), $(\text{MgFe})\text{O}.\text{SiO}_2$ requires more silica than olivine (ol), $2(\text{MgFe})\text{O}.\text{SiO}_2$, for the same amount of $(\text{MgFe})\text{O}$. With low silica, therefore, a substitution is made of one or more minerals which require less silica than the minerals employed in the straightforward calculations thus far considered.

Where silica is low the simplest adjustment is that illustrated by Analysis J. Here the minor inflexible molecules, ilmenite (il), and apatite (ap), are first calculated. In this analysis apatite cannot get its quota of Cl or F, for these elements have not been determined. The molecular weight is however taken as 336, and the percentage weight of the mineral obtained by multiplying the amount of P_2O_5 by 336. The table on p. 258 for the percentage weights of apatite is based on a molecular weight of 336, F or Cl having been available. Al_2O_3 is present in sufficient amount to allow with silica for the formation of orthoclase (or), albite (ab), and anorthite (an). After the allotments for magnetite (mt), and diopside (di), there remain of MgO 67, and of FeO 20 units. The silica available at this point is 62. This is not enough to make hypersthene with the MgO and

FeO, for which 87 molecular proportion units of SiO_2 would be needed. If we should take the MgO and FeO with silica for olivine (ol), $2(\text{MgFe})\text{O}.\text{SiO}_2$, in the proportion 2:1, then silica would be left over in amount equal to 18 units. The formulated method for calculating the norm does not admit of our making olivine at this point with $(\text{MgFe})\text{O}$ and silica, and then calling the remaining silica quartz. This accords with the fact that quartz and olivine are very rarely found together in igneous rocks. What we do is to divide the MgO, FeO, and available silica between hypersthene and olivine, making use of two simple algebraic equations.

$$\begin{aligned} &\text{Let } x = \text{the number of hypersthene molecules} \\ &\text{and } y = \text{the number of olivine molecules;} \\ &\text{then } x + y = \text{the number of units of } (\text{MgFe})\text{O} \\ &\text{and } x + \frac{y}{2} = \text{the number of units of } \text{SiO}_2, \\ &\text{or } x + y = 87 \\ &\text{and } x + \frac{y}{2} = 62 \\ &\frac{y}{2} = 25 \\ &y = 50 = \text{molecules of olivine} \\ &\text{and } x = 37 = \text{molecules of hypersthene.} \end{aligned}$$

MgO and FeO are to be introduced in hypersthene and in olivine in the same ratio in which they were used in diopside. The ratio in this case is 20:67 or, nearly, $1:3\frac{1}{2}$.

It is to be noted in connection with the use of the tables that olivine is the sum of two parts, $2\text{MgO}.\text{SiO}_2$ and $2\text{FeO}.\text{SiO}_2$. We look up the first of these on p. 255, and use in looking it up one-half the amount of MgO units, i. e., $\frac{39}{2}$, not 39.; and in the same way we look up one-half the amount of FeO units, or $5\frac{1}{2}$, not 11, on p. 256, and add our findings together for olivine.

Analysis K illustrates the same points as J, but in it pyrite is introduced, FeS_2 having been present in the rock.

$$\begin{aligned} &x = \text{the number of hypersthene molecules} \\ &y = \text{the number of olivine molecules} \\ &x + y = 139 = (\text{MgFe})\text{O} \\ &x + \frac{y}{2} = 88 = \text{SiO}_2 \\ &\frac{y}{2} = 51, y = 102, \text{ and } x = 37. \end{aligned}$$

ANALYSIS J
ANDOSE (DIORITE). *Professional Paper 14*, p. 272, No. 11
Crazy Mountains, Mont.

Percentage	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	H ₂ O	Sum	Femic Minerals
Molecular Proportions	.846	.196	.020	.066	.087	.155	.065	.020	.020	.006	.077	100.13	
Remainder at this point → SiO ₂ 62 MgO 67 FeO 20	120	20		20		18		20	20	6			il 3.0 ap 2.0 .006 X 336
	390	65				III	65				or 11.1 ab 34.1 an 30.9		mt 4.6 (CaO.SiO ₂ 3.02 MgO.SiO ₂ 2.000 FeO.SiO ₂ .79
	222	III	20	20		26							di 5.8 { MgO.SiO ₂ 2.800 FeO.SiO ₂ 1.19
	52			6	20								hy 4.0 { MgO.SiO ₂ 2.800 FeO.SiO ₂ 1.19
	37			9	28								ol 3.9
	25			11	39								Fem. 23.3
											Sal. 76.1 Fem. 23.3 H ₂ O .77		
											Sum 100.17		

NOTE.—With FeO, MnO .001 has been added in. BaO, .002 have been added to CaO.

ANALYSIS K
 HESSE (AMPHIBOLE GABBRO). *Classification of Igneous Rocks*, p. 199
 Big Trees Quadrangle, Cal.

Percentage	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	FeS ₂	H ₂ O	Sum	
	47.27	20.82	1.85	4.20	6.44	13.02	2.75	0.22	0.02	0.74	0.20	1.35	99.84	
Molecular Proportions	.788	.204	.011	.059	.101	.232	.044	.002	.011	.005			Salic Minerals	Femic Minerals
				11		15		2	11	5		or	1.1	ap
	12	2					44					ab	23.1	il
246	44	158				158						an	43.9	
306			11	11										mt
														di
	118			11	48	59								2.6
				11										13.1
														6.84
														4.800
														1.45
														1.45
														3.000
	37			7	30									.92
														5.80
	51			19	83									1.94
												Sal.	68.1	FeS ₂
												Fem.	30.8	
												H ₂ O	1.35	Fem. 30.8
												Sum	100.25	

It is to be noted that with quartz we will not have olivine in the norm and vice versa.

By making some hypersthene and some olivine, therefore, we can allow for a small shortage of SiO_2 . If we attempt to calculate Analysis L in the same manner it is found that after making orthoclase (or), albite (ab), anorthite (an), magnetite (mt), diopside (di), and olivine (ol), 219 more units of silica have been called for than are available. The silica deficit is too great to be treated as in the preceding example.

ANALYSIS L. TENTATIVE

LAURDALOSE (SYENITE PEGMATITE). *Professional Paper 14*, p. 296, No. 14
Stoksund, Norway

Percentage {	SiO_2 53.81	Al_2O_3 19.69	Fe_2O_3 .620	FeO .363	MgO .085	CaO .173	Na_2O 7.77	K_2O 4.58	H_2O 1.52	Sum 99.78	
Molecular Proportions	.897	.193	.039	.050	.021	.031	.125	.049			
	294 750 38	49 125 19					125	49			
			39	39	8	12					mt di ol
	24 10			4 7	13						
	1,116 SiO_2 have been allotted at this point. 897 available SiO_2										
	219 SiO_2 deficit for this distribution										

In the tentative distribution albite (ab) calls for 6×125 , or 750, SiO_2 . Nephelite would use up only 250, or 2×125 , SiO_2 . If we allot in the first place (holding out the soda, Na_2O , 125, and equal Al_2O_3 , 125) the proper amounts of the various oxides for orthoclase (or), anorthite (an), magnetite (mt), diopside (di), and olivine (ol), we shall have 531 units of SiO_2 left, to go with the 125 Na_2O and 125 Al_2O_3 . What we do then is to make a certain amount of albite and a certain amount of nephelite. It is to be remembered that in any allotment of Na_2O and Al_2O_3 to albite (ab), $\text{Na}_2\text{O}.\text{Al}_2\text{O}_3.6\text{SiO}_2$, and nephelite (ne), $\text{Na}_2\text{O}.\text{Al}_2\text{O}_3.2\text{SiO}_2$, the ratio of Na_2O to Al_2O_3 will be as 1:1. Being silica poor we made olivine (ol), with $(\text{MgFe})\text{O}$ and not hypersthene. The formulas for the distribution of Na_2O , Al_2O_3 , and SiO_2 between albite and nephelite are as follows:

$$\begin{aligned}
 &\text{Let } x = \text{the number of albite molecules} \\
 &\text{Let } y = \text{the number of nephelite molecules} \\
 &\text{then } x + y = \text{Na}_2\text{O} = \text{Al}_2\text{O}_3 \\
 &\text{and } 6x + 2y = \text{SiO}_2 \\
 &\quad x + y = 125 \\
 &\quad 6x + 2y = 531 \\
 &\quad 2x + 2y = 250 \\
 &\text{subtracting } 4x = 281 \\
 &\quad x = 70 \text{ molecules of albite} \\
 &\quad y = 55 \text{ molecules of nephelite.}
 \end{aligned}$$

It is clear that with nephelite in the norm we shall not have quartz.

Analysis M proceeds on the same lines as L except that the minor inflexible molecule zircon (Z), is first introduced, taking $\text{ZrO}_2 = \text{SiO}_2$ in accordance with its formula $\text{ZrO}_2 \cdot \text{SiO}_2$.

In N we have a case with SiO_2 still lower than in M. If we attempt to calculate it in the same way as L and M we find that we have run over on SiO_2 by 21 units, holding out $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3$, 45, for albite and nephelite, and making the allotments for apatite, orthoclase, anorthite, magnetite, diopside, and olivine. We have therefore no SiO_2 with which to make even nephelite with the 45 $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3$ held out in the beginning.

There is not enough SiO_2 therefore to begin the calculation by making orthoclase. This case is analogous to the situation in L and M where Na_2O is distributed between albite and nephelite. We proceed by holding out all the K_2O and equal Al_2O_3 for a certain amount of orthoclase, and a certain amount of leucite ($\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$), which calls for less SiO_2 than orthoclase does. These minerals will each use up K_2O and Al_2O_3 in the ratio 1:1. The Na_2O is allotted with Al_2O_3 and SiO_2 to nephelite. This is much lower in SiO_2 than albite is. Anorthite, magnetite, diopside, and olivine are then made. The SiO_2 remaining over is 369. This is given to the $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3$, previously set aside, for orthoclase and leucite, by means of the equations where

$$\begin{aligned}
 &x = \text{the number of molecules of orthoclase} \\
 &\text{and } y = \text{the number of molecules of leucite} \\
 &\quad x + y = \text{K}_2\text{O} \\
 &\text{and } 6x + 4y = \text{SiO}_2 \\
 &\text{Here } x + y = 80 \\
 &\quad 6x + 4y = 369 \\
 &\quad x = 24 \\
 &\text{and } y = 56.
 \end{aligned}$$

ANALYSIS M
Lujavrose (Lujaurite). *Professional Paper 14*, p. 303, last section, No. 1
Kangerdluarsuk, Greenland

Percentage {	SiO ₂ 51.62	Al ₂ O ₃ 15.63	Fe ₂ O ₃ 6.06	FeO 4.98	MgO 11	CaO 3.45	Na ₂ O 10.09	K ₂ O 4.19	ZrO ₂ 2.14	H ₂ O 2.12	Sum 100.61	Femic Minerals
Molecular Proportions	.860	.153	.038	.069		.062	.163	.045	.017	Salic Minerals		
17	17	45	38				108 { 15 93 38 17	45	17	z or ab ne	3.1 25.0 7.9 26.4	ac ns di ol
270 90 186 152 17						62						17.6 2.1 15.4 7.7
124 4				62 7	0 0							{ CaO.SiO ₂ 7.19 MgO.SiO ₂ .000 FeO.SiO ₂ 8.18 2MgO.SiO ₂ .00 2FeO.SiO ₂ .71
										Sal. Fem. H ₂ O	62.4 35.8 2.12	Fem. 35.8
										Sum	100.32	

ANALYSIS N. TENTATIVE

VESUVOSE (LEUCITE BASANITE). *Professional Paper 14*, p. 306, No. 2

Lava of 1872, Mount Vesuvius

Percent- age	SiO ₂ 47.65	Al ₂ O ₃ 19.28	Fe ₂ O ₃ 2.63	FeO 6.48	MgO 4.19	CaO 9.01	Na ₂ O 2.78	K ₂ O 7.47	P ₂ O ₅ 0.50	H ₂ O 0.24	Sum 100.23	
Molecular Proportions	.794	.189	.016	.090	.085	.161	.045	.080	.004	Salic Minerals		Femic Minerals
	480	80				12		80	4	or ab ne an		ap
	128	45 } 64				64	45 }					
	170		16	16		85						mt
	37			40	45							di
				34	40							ol
	815											
	794											
	21	SiO ₂										

With leucite and nephelite there will be no quartz nor will there be hypersthene. With leucite in the norm there will be no albite.

ANALYSIS N

VESUVOSE (LEUCITE BASANITE). *Professional Paper 14*, p. 306, No. 2

Lava of 1872, Mount Vesuvius

Percent- age	SiO ₂ 47.65	Al ₂ O ₃ 19.28	Fe ₂ O ₃ 2.63	FeO 6.48	MgO 4.19	CaO 9.01	Na ₂ O 2.78	K ₂ O 7.47	P ₂ O ₅ 0.50	H ₂ O 0.24	Sum 100.23	
Molecular Proportions	.794	.189	.016	.090	.085	.161	.045	.080	.004	Salic Minerals		Femic Minerals
	144	80 { 24 224 } 56				12		80 { 24 56 }	4	or lc ne an	13.3 24.4 12.8 17.8	ap 1.3
	90	45				64	45					
	128	64	16	16								mt
	170			40	45	85						di
	37			34	40							ol 3.7 19.6 6.3
										Sal. 68.3 Fem. 30.9 H ₂ O .24		Fem. 30.9
										Sum 99.44		

Analysis O is like N, where K₂O goes partly to orthoclase and partly to leucite, but here we make the minor inflexible molecules

ilmenite (il), fluorite (ft), sodalite (so), noselite (no), and calcite (cc), at the outset. (See note at end of paper.) The formula for sodalite is $3(\text{Na}_2\text{O}.\text{Al}_2\text{O}_3.2\text{SiO}_2).2\text{NaCl}$ and that for noselite is $2(\text{Na}_2\text{O}.\text{Al}_2\text{O}_3.2\text{SiO}_2)\text{Na}_2\text{SO}_4$. Sodalite is therefore like the nephelite molecule taken three times with 2NaCl added. Where Cl occurs in notable amount with P_2O_5 present it is first allotted to apatite (see Analysis I), and the remainder then takes half as many units of Na_2O for 2NaCl in sodalite. One-half the number of units of Cl is the key. By multiplying this number, .010, by 969 (the molecular weight of sodalite), the percentage weight of sodalite (so) is obtained. Where SO_3 is present it takes an equal amount of Na_2O for Na_2SO_4 in noselite (no). The number of units of SO_3 is the key. By multiplying this number, .009, by 699 (the molecular weight of noselite), we get the percentage weight of noselite. In this calculation the nephelite molecules in sodalite (15), and in noselite (9), have been lumped in with nephelite. CO_2 when present in a rock usually points to a weathered condition in the rock, the mineral then being present as an alteration product. Where CO_2 occurs in a rock and is not a product of alteration, calcite is an original mineral constituent. In Analysis O we allot to 6 units of CO_2 as many units of CaO for calcite (cc), $\text{CaO}.\text{CO}_2$, the ratio between CaO and CO_2 being 1:1.

In the foregoing examples of calculation a shortage of SiO_2 was met by distributing $\text{Na}_2\text{O}.\text{Al}_2\text{O}_3$ between albite and nephelite, after making orthoclase with $\text{K}_2\text{O}.\text{Al}_2\text{O}_3$; or the shortage was provided against, after making nephelite, by distributing $\text{K}_2\text{O}.\text{Al}_2\text{O}_3$ between orthoclase and leucite. With SiO_2 too low for either of these alternatives we may allot $\text{K}_2\text{O}.\text{Al}_2\text{O}_3$ to leucite and $\text{Na}_2\text{O}.\text{Al}_2\text{O}_3$ to nephelite, using up in this way a relatively small amount of SiO_2 . This is the procedure in Analysis P, where we make leucite, nephelite, anorthite, magnetite, diopside, and olivine, only to find that we have run over by 74 units of SiO_2 . In making diopside we used 302 SiO_2 . If now we take CaO from diopside, turn the MgO and FeO thus set free into more olivine, and use the lime (with the requisite amount of SiO_2) in ackermanite (am), $4\text{CaO}.3\text{SiO}_2$, which by its formula uses up less SiO_2 for the same amount of CaO than diopside does, we can do away with the SiO_2 deficit. When the ratios of $\text{CaO}:\text{SiO}_2$ in diopside, 1:2 (or 4:8), and in ackermanite, 4:3, are considered, it

ANALYSIS P. TENTATIVE

ALBANOSE (LEUCITITE). *Professional Paper 14*, p. 350, sec. 4, No. 1
Alban Hills, Italy

Percentage {	SiO ₂ 45.99	Al ₂ O ₃ 17.12	Fe ₂ O ₃ 4.17	FeO 5.38	MgO 5.30	CaO 10.47	Na ₂ O 2.18	K ₂ O 8.97	TiO ₂ 0.37	H ₂ O 0.45	Sum 100.65	
Molecular Proportions	.767	.168	.026	.075	.133	$\frac{.187}{.002 \text{ BaO}} \frac{.189}{.189}$.035	.095	.005	Salic Minerals		Femic Minerals
	380 70 76	95 35 38		5			35	95	5	lc ne an		il
	302 13		26	26 38 6	113 20	151						mt di ol
	841 767											
	74 Deficit in SiO ₂											

at once appears that ackermanite (am), is the mineral lower in SiO₂ for the same amount of CaO. By taking 96 CaO from the diopside and using with it 72 SiO₂ we make 24 molecules of ackermanite, i. e., 24 (4CaO.3SiO₂). By recalculating for new diopside and putting in the 24 molecules of ackermanite (am) (calling for 72 SiO₂ with 96 CaO), we find that as the result there is no deficit of SiO₂. To ascertain just the right amount of ackermanite to be introduced we make use of the simple formula where

y = the deficit of SiO₂

$\frac{y}{3}$ = the number of ackermanite molecules to be made.

It appears on trial of all such cases that the deficiency in SiO₂ is exactly allowed for when the number of ackermanite molecules made with CaO taken from diopside equals one-third of the SiO₂ deficit, and in consequence we take lime away from diopside equal to four times the number of ackermanite molecules. Numerically it is found that for every unit of CaO taken from diopside and used in ackermanite we gain three-fourths of a unit in silica, though the process involves the making of new olivine which itself uses up silica. So then to make up a deficit of 74 SiO₂ we need to take 96 CaO from diopside, 96 CaO + 72 SiO₂ making 24 molecules of ackermanite.

In P, therefore, we first allot for ilmenite, leucite, nephelite, anorthite, and magnetite. Then, for ackermanite, 96 CaO units are taken from diopside previously made, and used with 72 SiO₂ for ackermanite in accordance with the formula 4CaO.3SiO₂. In looking up the percentage weight of ackermanite (am), in the table on p. 256 the unit of calculation is 24, not 96; i. e., it is one-fourth the molecular proportion of CaO in the ackermanite. The 55 units of CaO left over from the original diopside assignment are allotted for new diopside, and the MgO and FeO thus set free go to olivine.

It should be noted that in this analysis after making diopside there is no excess of CaO to be set aside for the making of wollastonite (cf. Analysis F). In the following example (Q), 95 molecular-proportion units of CaO are left over after the making of diopside for wollastonite.

The calculation of Analysis Q differs from that of the preceding example, as was noted just above, in that CaO in the tentative allotment is found to cover the MgO and FeO for diopside and to remain over after this in amount equal to 95 units. These are given to wollastonite (wo), CaO.SiO₂. The silica deficit is 78. By turning 92 of the 95 CaO of the wollastonite into ackermanite (making in such a case 23 molecules of ackermanite calling for 92 CaO and 69 SiO₂), we can do away with a deficit of silica equal to 23. If then our silica deficit were not 78 as it is in this analysis but only 23 or less, enough CaO set aside for wollastonite could be converted into ackermanite in this manner to do away with the silica deficit. The formula used is, where y = the silica deficit, y = as well the number of ackermanite molecules to be made. This alternative is not open to us in this analysis but it is clear how such calculations are to be treated when they arise. In this case, with insufficient molecules of wollastonite to satisfy the deficit of SiO₂ by their conversion into ackermanite, the molecules of both diopside and wollastonite are to be recalculated to make new diopside, new olivine, and ackermanite by the following equations.

Let x = the molecules of new diopside
 y = the molecules of ackermanite
 z = the molecules of new olivine.

Then $2x + 3y + \frac{z}{2}$ = the available SiO₂

$x + 4y$ = the available CaO

$x + z$ = the available (MgFe)O.

ANALYSIS P
ALBANOSE (LEUCITITE). *Professional Paper 14*, p. 350, sec. 4, No. 1
Alban Hills, Italy

Percentage	SiO ₂ 45.99	Al ₂ O ₃ 17.12	Fe ₂ O ₃ 4.17	FeO 5.38	MgO 5.30	CaO 10.47	Na ₂ O 2.18	K ₂ O 8.97	TiO ₂ 0.37	H ₂ O 0.45	Sum 100.65	
Molecular Proportions	.767	.168	.026	.075	.133	<div>.187</div> <div>BaO</div> <div>.002</div> <div>.189</div>	.035	.095	.005	Salic Minerals		Femic Minerals
	380	95		5		38	35	95	5	lc ne an	41.4 9.9 10.6	il mt am
	70	35	26	26		96						
	76	38				55						
	72			14	41							
	110			30	92							
	61											
										Sal. Fem. H ₂ O	61.9 36.3 .45	Fem. 36.3
										Sum	98.65	

{ CaO.SiO₂ 6.38
 MgO.SiO₂ 4.100
 FeO.SiO₂ 1.85
 2MgO.SiO₂ 6.44
 2FeO.SiO₂ 3.06

In this calculation the available SiO_2 is 309, the CaO 241, and the $(\text{MgFe})\text{O}$, 146.

$$\text{Therefore (1) } 2x + 3y + \frac{z}{2} = 309$$

$$(2) \quad x + 4y = 241$$

$$\text{and (3) } x + z = 146.$$

From (2), multiplying by 2,

$$2x + 8y = 482;$$

$$(1) \quad 2x + 3y + \frac{z}{2} = 309;$$

$$\text{subtracting } 5y - \frac{z}{2} = 173$$

$$\text{or } 10y - z = 346.$$

$$\text{Again (2) } x + 4y = 241$$

$$(3) \quad x + z = 146;$$

$$\text{subtracting } 4y - z = 95$$

$$10y - z = 346$$

$$4y - z = 95$$

$$y = 42, \text{ ackermanite}$$

$$x = 73, \text{ new diopside}$$

$$z = 73, \text{ new olivine.}$$

With silica still lower than in Analysis Q we make such a calculation as is given in Analysis R. Here, after the assignment for ilmenite the K_2O , 79 units, is held out with equal $\text{Al}_2\text{O}_3 \cdot \text{Na}_2\text{O}$, takes Al_2O_3 as far as it is available (17), and SiO_2 for nephelite. Extra Na_2O , 9, takes Fe_2O_3 and SiO_2 for acmite. Fe_2O_3 remaining takes equal FeO for magnetite. All the CaO , 296 units, is calculated as ackermanite, and MgO and FeO remaining over take SiO_2 for olivine. Silica is left equal to 204 units. This is distributed with the 79 $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3$ held out (ante), between leucite and kaliophilite (kp), $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$. The equations are

$$x + y = \text{K}_2\text{O}$$

$$4x + 2y = \text{SiO}_2$$

where x = the number of molecules of leucite

and y = the number of molecules of kaliophilite.

$$(1) \quad x + y = 79, \text{ K}_2\text{O}$$

$$(2) \quad 4x + 2y = 204, \text{ SiO}_2.$$

$$\text{From (1) } 2x + 2y = 158$$

$$2x = 46$$

$$x = 23, \text{ leucite molecules}$$

$$y = 56, \text{ kaliophilite molecules.}$$

Kaliophilite takes only half as much silica to go with a like amount of $K_2O \cdot Al_2O_3$ as leucite would take, and only a third as much as orthoclase.

ANALYSIS R

VENANZOSE (EUKTOLITE). *Professional Paper 14*, p. 357, last analysis
San Venanzo, Umbria, Italy

Percent- age	SiO ₂ 41.43	Al ₂ O ₃ 9.80	Fe ₂ O ₃ 3.28	FeO 5.15	MgO 13.40	CaO 16.62	Na ₂ O 1.64	K ₂ O 7.40	TiO ₂ 0.29	H ₂ O 1.11	Sum 100.12	
Molecular Proportions	.691	.096	.021	.072	.335	.296	.026	.079	.004	Salic Minerals		Femic Minerals
	92 112 34 36 222 195	79 { 23 56 17	9 12	4 12 56	 335	 296	17 9	79 { 23 56	4	lc kp ne 10.0 17.7 4.8		il .6 ac 4.2 mt 2.8 am 29.1 ol 29.2
										Sal. 32.5 Fem. 65.9 H ₂ O 1.11		Fem. 65.9
										Sum 99.51		

It will be noted that the series of analyses from J to R inclusive illustrates a series of alternative methods for dealing with low SiO₂. A slight deficit may be adjusted between hypersthene and olivine. By this device we can do away with a silica deficit equal to one-half (MgFe)O. A larger deficit may be provided against by making albite with nephelite after having made orthoclase, under the conditions given above. This saving of silica amounts to a little less than four times the Na₂O. A still larger deficiency in SiO₂ may be provided for by allotting for orthoclase and leucite after making nephelite. Our making nephelite first in this case saves us an amount of SiO₂ equal to four times the units of Na₂O, and the subsequent distribution saves a little less than two times the amount of K₂O. With silica still lower it is necessary after making leucite and nephelite, thus saving two times the units of K₂O plus four times the Na₂O, to bring in ackermanite, a device which then saves three fourths of a unit of SiO₂ for every unit of CaO taken from diopside for ackermanite, or one silica on every four converted from wollastonite

into ackermanite. With silica lower still it is necessary to expend as little of it as possible, making nephelite and ackermanite and distributing the silica then remaining between leucite and kaliophillite.

In Analysis S which is calculated like Analysis P, the first of the minor inflexible molecules to be made is chromite (cm), $\text{FeO} \cdot \text{Cr}_2\text{O}_3$, the ratio between FeO and Cr_2O_3 being as 1:1. After ilmenite, which follows, we make perovskite (pf), $\text{CaO} \cdot \text{TiO}_2$, with $\text{CaO}:\text{TiO}_2$ as 1:1. If silica has been present in abundance we should have made titanite instead of perovskite. (Cf. Analysis I.)

With the lowest-known ranges of SiO_2 , in rocks in which aluminous spinel may form, Al_2O_3 and $(\text{MgFe})\text{O}$ being in excess, Al_2O_3 left over after making the feldspars, nephelite, or leucite, is corundum. MgO and FeO uncombined after their allotment to such minerals as magnetite and ilmenite may have to be entered with the femic minerals simply as MgO and FeO. Their percentage weights are determined by multiplying them by the molecular weights of MgO and FeO. Such a case is illustrated in Analysis T.

ANALYSIS T

(MAGNETITE SPINELLITE). *Professional Paper 14*, p. 368, last analysis
Routivaara, Finland

Percent- age	SiO_2 4.08	Al_2O_3 6.40	Fe_2O_3 33.43	FeO 34.58	MgO 3.89	CaO 0.65	Na_2O 0.29	K_2O 0.15	TiO_2 14.25	Cr_2O_3 0.20	H_2O 1.32	Sum 99.71	
Molecular Proportions	.068	.063	.210 note	.480	.097	.011	.005	.002	.176	.001	Salic Minerals		Femic Minerals
	12 30 22	2 5 11 45	210	176 210 94	97	11	5	2	176		or ab an C	1.1 2.6 3.1 4.6	il 26.8 mt 48.7 MgO 3.9 FeO 6.9 Fem. 86.3
											Sal. 11.4 Fem. 86.3 H_2O 1.32		
											99.02		

NOTE.— Cr_2O_3 , .001, has been added to Fe_2O_3 .

The student in calculating the analyses given in *Professional Paper 14* should not expect to agree exactly in all cases with the

calculated norms. Where additions as those of small amounts of BaO and SrO to CaO have not been made, slight discrepancies may result all along the line. Numerically the allotment to such minerals as diopside, hypersthene, and olivine may vary by a single unit one way or the other in MgO and FeO. The application of the methods of calculation given in the *Quantitative Classification of Igneous Rocks* should however be precise, the end in view being the correct placing of a given rock where it belongs in the scheme of classification. The method of calculating the norm is necessarily arbitrary in order that concordant results may be obtained by all who make use of it. It should be borne in mind, however, that it agrees with the great body of our observations on the occurrence of minerals in the igneous rocks. The work of calculation has therefore a peculiar value for the student, aside from his needs in classifying rocks, for it directs his thought toward the relations obtaining among the phenomena in cooling rock magmas. It brings home to him why it is that we do not have such an occurrence as that of quartz and nephelite together. It points out to him, for instance, the significance of the presence in a rock of such minerals as corundum, acmite, or perovskite rather than titanite, and it does much to make clear to his mind the significance of each of the mineral molecules occurring in the igneous rocks.

NOTE.—In "The Roman Comagmatic Region," *Publication 57 of the Carnegie Institution of Washington*, Dr. H. S. Washington has stated on p. 15 a modification of the method of calculation proposed by the authors of the quantitative system. This has to do with the normative minerals, sodalite and noselite. These mineral molecules are split up, and in their stead a statement is made in the norm of the amounts of halite (Hl), NaCl, and thenardite (Th), Na_2SO_4 . SO_3 takes an equivalent number of molecular units of Na_2O to form thenardite, and Cl takes one-half its number of molecular units of Na_2O to form halite. "The soda which was previously combined with the sodium chloride and sulphate remains with the rest in calculating the norm, and, if necessary, is distributed between albite and nephelite in the usual way. An advantage of this method of procedure is that it minimizes the influence of the small amounts of Cl and SO_3 usually found, which is very great if they bind up in the norm a much greater amount of soda and silica."